CHALLENGES, LESSONS AND METHODS FOR LEAVING A RESIDUAL IMPACT

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ABSTRACT

What happens when you combine earthquakes causing significant and widespread damage to water supply infrastructure, and a water reform resulting from the contamination event in Havelock North? The answer is retrofitted chlorination infrastructure. Retrofitting of chlorine dosing is a task that faces water suppliers around New Zealand. It is a requirement under the Drinking Water Quality Assurance Rules 2022 (released 25 July 2022) to provide residual disinfection unless a specific residual exemption has been granted.

The Christchurch drinking water supply scheme contains earthquake damaged and aging infrastructure and changes have been observed in source water quality. The Water Reform process has enabled a risk-based approach and has resulted in a change in the standards and rules for drinking water treatment, while maintaining a continued focus on the safety of consumers. Numerous operational issues have been identified across the Christchurch scheme, which have been assessed by Christchurch City Council (CCC) as presenting an unacceptable residual risk to consumers. As a result, CCC have embarked on a programme of works to upgrade temporary chlorine infrastructure to permanent standby chlorination across the scheme. Taumata Arowai (Water Services Regulator for New Zealand) have signalled that standby chlorination is required to gain a chlorine exemption.

Chlorine dosing for both primary and secondary disinfection is commonly used around New Zealand and throughout the world. There are well established processes for the installation of chlorination and the related equipment and infrastructure as part of new water treatment plants (WTP) or upgrades of existing schemes which are already chlorinated. However, the instruction manual on considerations around retrofitting chlorination is considerably thinner, especially retrofitting permanent installations.

This paper discusses the challenges associated with the addition of chlorine (an oxidising agent) into an existing treatment and reticulation system which has been operational for some time and was not originally designed for chemical dosing. These challenges include:

- Pitting and corrosion in relation to pipe materials.
- Solubilising legacy deposits of dissolved constituents resulting in a change in drinking water composition and characteristics.
- Sloughing of biofilm leading to colour and taste changes for consumers.

This paper aims to provide practical insights into the considerations necessary when completing this retrofitting exercise. Chlorine system retrofitting considerations also present valuable lessons learned which may be applicable to installations of fluoridation equipment, a topic numerous water suppliers across New Zealand are presently considering.

KEYWORDS

Chlorine, drinking water, retrofitting, oxidising agent

PRESENTER PROFILE

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Ian Baker is a Process Engineer at Christchurch City Council responsible for the operational delivery of CCC's "temporary chlorination units". Trained as an environmental scientist with experience of drinking water treatment and water quality monitoring in the Netherlands, Egypt and New Zealand.

1 INTRODUCTION

The 2010 and 2011 Canterbury earthquakes caused disruption and damage to the Christchurch City water supply infrastructure. This resulted in the requirement for temporary/emergency repairs immediately following the earthquakes in order to continue to supply water. Following the initial response was a programme of assessment and rebuilding. Subsequently a drinking water contamination event occurred in 2016 in Havelock North. This has been the catalyst for a national overhaul of drinking water management in New Zealand. The Water Reform process has enabled a risk-based approach to drinking water management and has resulted in a change in standards and rules. These changes are based around ensuring the safety of consumers remains the focal point of drinking water supply.

Taking account for the events above and recognising that the Christchurch City Water Supply Scheme has aging infrastructure and changing source water quality, Christchurch City Council (CCC) made the decision in January 2018 to implement temporary chlorination. Numerous operational issues were also identified across the scheme, which have been assessed as presenting an unacceptable residual risk to consumers. In addition to this, Taumata Arowai (Water Services Regulator for New Zealand) have indicated that one of the requirements for gaining a residual exemption is to have permanent standby residual infrastructure in place. A residual exemption would allow the water supplier to supply drinking water without using residual disinfectants. An exemption may apply to all or part of a supply and can only be granted if it is consistent with the main purpose of the Water Services Act 2021 and if all other legislative requirements will be complied with, including the duty to provide safe drinking water.

CCC have embarked on a programme of works to upgrade temporary chlorine infrastructure to permanent standby chlorination across the scheme.

Some examples of changes made in the shift from temporary to permanent standby dosing infrastructure are as follows:

- Replacement of extension cords through hardwiring of power supply to chlorine system components (i.e. dosing pumps)
- Replacement of flexible dosing pipe with PVC Schedule 80
- Upgrade of radio technology from Sigfox to NB-IoT to allow for future installation of continuous monitoring equipment (this is currently in a trial phase to provide improved reporting and monitoring)
- Installation of purpose built sample points at both pump stations and network extremities for grab samples

In this paper we discuss the considerations when adding an oxidising agent (chlorine) to an existing system, CCC's approach to retrofitting permanent standby chlorination infrastructure and the lessons learned along the way.

2 CHLORINE DISINFECTION

2.1 DRINKING WATER STANDARDS

The Drinking Water Standards for New Zealand 2005 (Revised 2018) (Ministry of Health, 2018) (DWSNZ 2018) are the current standards and these define the minimum quality standards for drinking water in New Zealand until new standards come into effect in November 2022. The use of chlorine is covered under the bacterial compliance criteria which is split between drinking water leaving the treatment plant and drinking water in the distribution system.

With regards to drinking water in the distribution system, compliance can be achieved via *E.coli* monitoring only (criterion 6A) or through a combination of reduced *E. coli* monitoring paired with free available chlorine (FAC) monitoring (criterion 6B). Where chlorine is dosed, the maximum acceptable value (MAV) for chlorine is 5 mg/L and the minimum required residual 0.2 mg/L. The DWSNZ 2018 also outline requirements for sample sites, frequency of sampling and number of samples. It should be noted that the DWSNZ 2018 do not have an explicit requirement for drinking water supplies to provide residual disinfection.

As part of the Water Reform, Taumata Arowai have been established. Taumata Arowai have developed new rules and standards which come into effect on 14 November 2022. The information which is contained within the current DWSNZ 2018 has been amended and separated out into three documents: Drinking Water Standards 2022, Drinking Water Aesthetic Values 2022 and Drinking Water Quality Assurance Rules 2022 (DWQAR). In relation to chlorination a key change from the current DWSNZ 2018 is that the DWQAR in alignment with the Water Services Act 2021 requires all large schemes (>500 people) to provide residual disinfection in the reticulation network. As discussed in Section 1 it is possible to apply for an exemption from the requirement for residual disinfection.

2.2 CHLORINE RESIDUAL

Chlorine is the most commonly used chemical for disinfection of water supplies (Safe Drinking Water Foundation, 2022), it can be dosed to provide primary disinfection and/or residual disinfection. For the purposes of this paper, the focus is on residual disinfection where chlorine is dosed to prevent microbial re-growth and help prevent recontamination of water throughout the distribution system.

As an oxidising agent, when added to water some of the chlorine will react with organic and inorganic materials in the water. The chlorine which has reacted has been consumed and is no longer available for disinfection. These initial reactions account for the chlorine demand of the water. Once chlorine demand is met, total chlorine remains. Total chlorine is the sum of combined chlorine and FAC. Combined chlorine is the chlorine which has combined with nitrogenous or other organic compounds (Centers for Disease Control and Prevention, 2022). FAC is the chlorine residual that is available for disinfection after the chlorination breakpoint has been reached.

This is often represented as free available chlorine equivalent (FACE) which is calculated from the measured FAC. FACE is the FAC concentration that would have the same disinfecting power as the chlorine solution would have when adjusted to a pH of 8.0. It accounts for the fact that the disinfection (i.e. oxidizing) capacity of chlorine is strongly pH dependent, because the form (speciation) of the disinfectant in the water changes with pH (DWSNZ, 2018).

The reactions discussed above are represented by the breakpoint curve shown in Figure 1, with each of the points explained below (American Water Works Association, 2006):

- Zone 1 – The presence of reducing agents and other inorganic chlorine demand causing compounds will consume any initial chlorine dosage, which results in zero chlorine residual until the demand is satisfied.

- Zone 2 – Once this initial demand is met, in the presence of ammonia and other organic compounds any additional dosage will be measured as combined chlorine residual. This residual will increase in proportion to the increase in dosage. In this zone monochloramine is the primary chlorine form.

- Zone 3 – Chlorine to ammonia molar ratio surpasses 1:1 and more and more dichloramine is formed, the dosage/residual relationship will cease to be linear and the amount of combined and total residual increase will flatten out. In this zone the proportion of dichloramine increases to a point where it, alongside any chloro-organic compounds that may have formed begin to decompose.

- Zone 4 – Subsequent increases in chlorine dosage will covert an increasing proportion of monochloramine to dichloramine, which subsequently decomposes resulting in an approximate residual decrease of 2 mg/L for each milligram per litre of chlorine added.

- Breakpoint – This continuing decrease of total residual will taper off and the chlorine residual will reach a minimum point. This is the breakpoint and represents the point in the treatment process at which all ammonia compounds and most chloro-organic compounds have been oxidised.

- Zone 5 – Any further chlorine addition will increase the residual chlorine as FAC. This is the operational zone when aiming for residual chlorine.

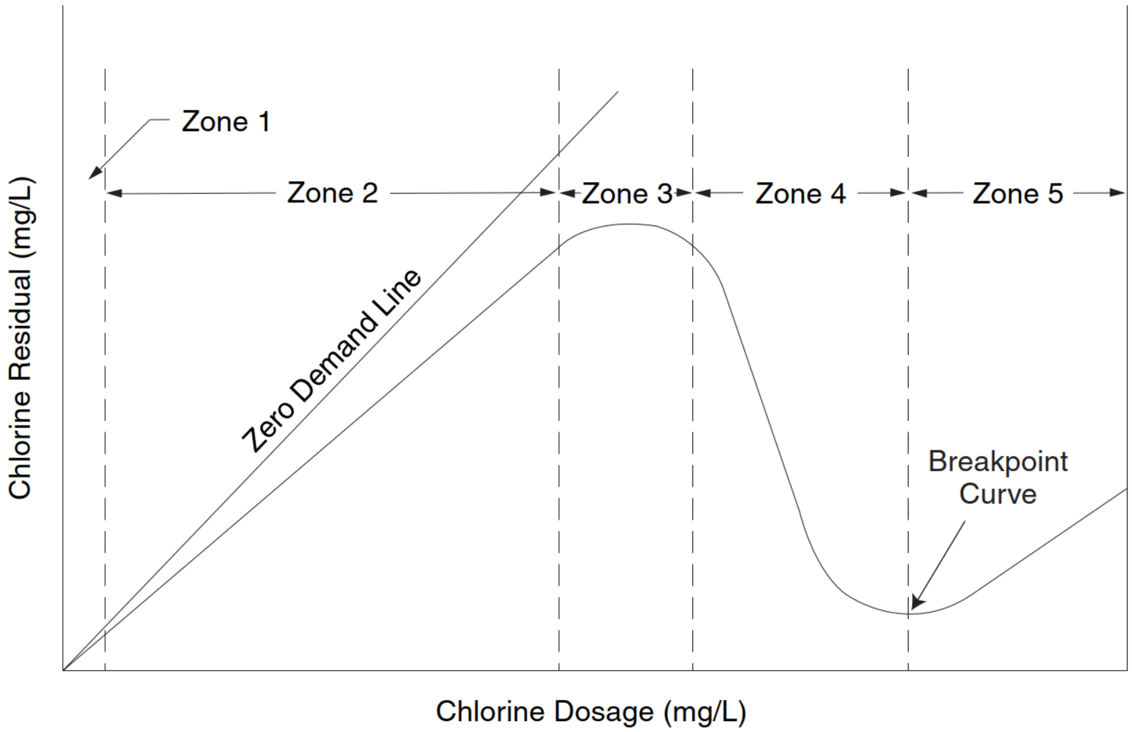


Figure 1: Breakpoint Curve (American Water Works Association, 2006)

Chlorine reacts both with the water but also with the treatment plant and distribution infrastructure.

3 IMPACTS ON THE WATER SUPPLY SYSTEM

3.1 CORROSION OF PIPES

Pipes and other infrastructure (i.e. pumps and reservoirs) used to distribute drinking water are typically made of plastic, concrete or metal (steel, galvanized steel, ductile iron and copper). Each material in a drinking water system is affected by contact with chlorinated water in its own characteristic manner. For example, plastic and concrete tend to be more resistant to corrosion than metals. Metal pipes are most susceptible to corrosion, with corrosion tendency varying between the different metal pipe types (Centers for Disease Control and Prevention, 2013). Cementitious infrastructure (i.e. reservoirs) can also deteriorate in the presence of an oxidant (Młyńska et al., 2019), particularly if there is any exposed rebar in concrete water-baring structures. Corrosion can occur at the water treatment plant, in the distribution system and through household plumbing.

In general, chlorine is considered to be a corrosive agent in water. There are several different chemicals which are commonly used for chlorine disinfection, including chlorine gas (liquified under pressure) and sodium hypochlorite (NaOCl).

Both of these serve the same function in terms of disinfection however chlorine gas acts as an acid decreasing the pH of water whereas sodium hypochlorite is alkaline, slightly increasing the pH of water (Choi, 2021). The pH and alkalinity of the water also have an impact on how corrosive the water is; typically, the lower the pH and alkalinity, the more corrosive a water will be.

Corrosion is the deterioration of a material as a result of its interaction with its surroundings. It is the process that converts a refined metal into a more chemically stable oxide. This is through electrochemical oxidation of a material in reaction with an oxidant. The corrosive electric potential is created by differences in the types of chemicals in the water or the surface of the pipe (McCafferty, 2010). Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability (Vendrell and Atiles, 2003).

One of the most common types of corrosion is uniform corrosion which usually takes place evenly over larger areas of the metal's surface and causes dissolved metals to enter the water (Tait, 2018) (Figure 2). The entry of these metals can create both aesthetic and health related problems and in some cases corrosion can be severe enough to cause leaks.

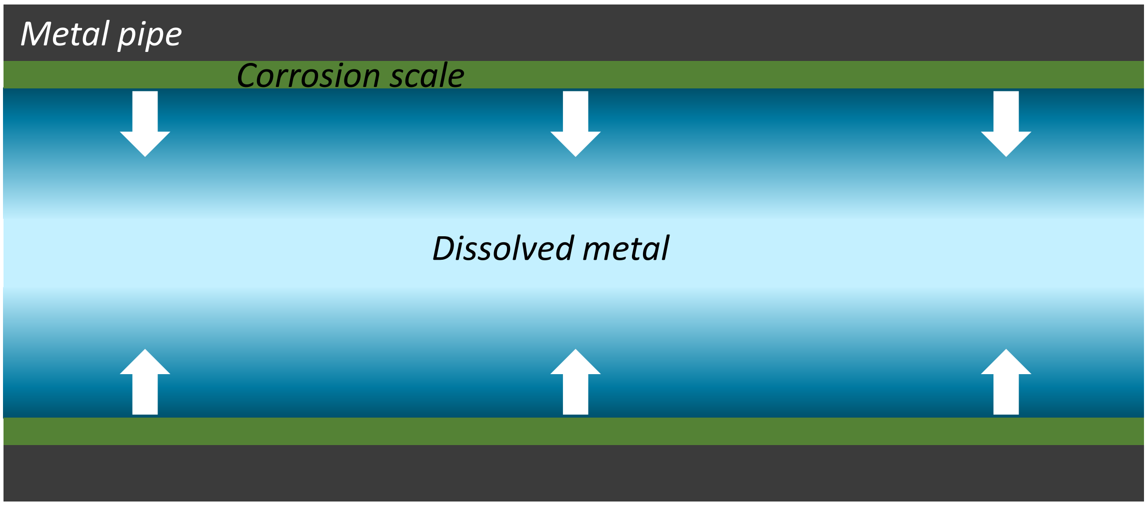


Figure 2: Uniform Corrosion

Pitting corrosion (Figure 3) is the localisation of corrosion to small areas or activation sites (Frankel, 1998). It occurs along surfaces where there are abrasions or the surface is not treated properly and can be associated with the release of particulates from the pipe wall which will be conveyed by the water. As with uniform corrosion, pitting corrosion can also cause premature failure of pipes.

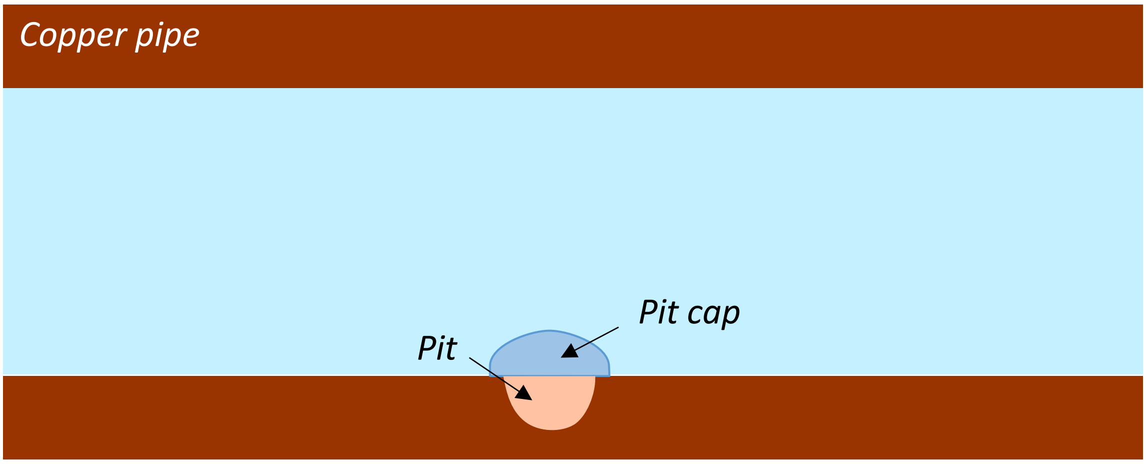


Figure 3: Pitting Corrosion

The oxidising characteristics are not unique only to metals, cementitious deterioration (Figure 4) can also occur. This is due to the dissolution of calcium carbonate, which is a component of the cement.

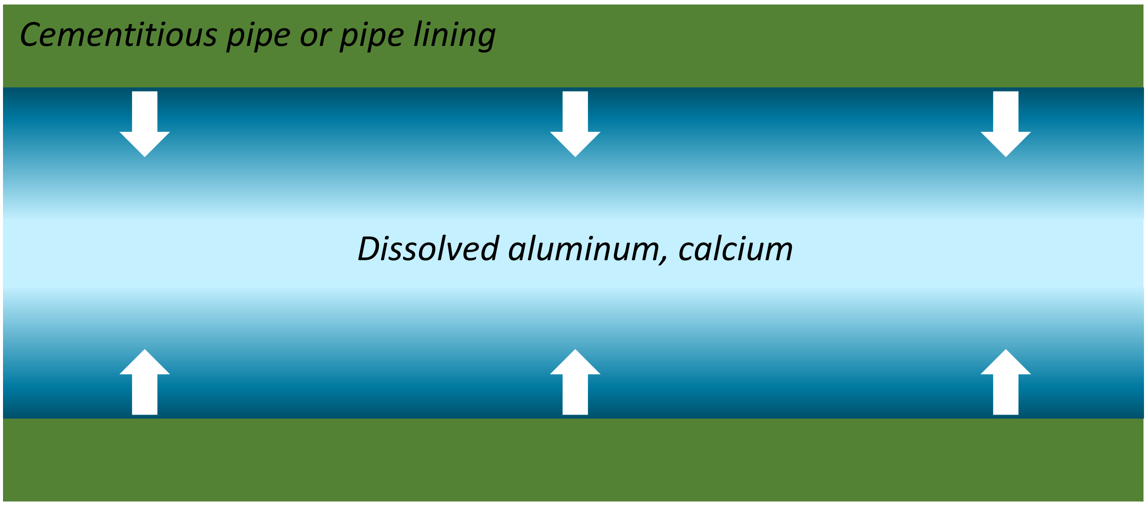


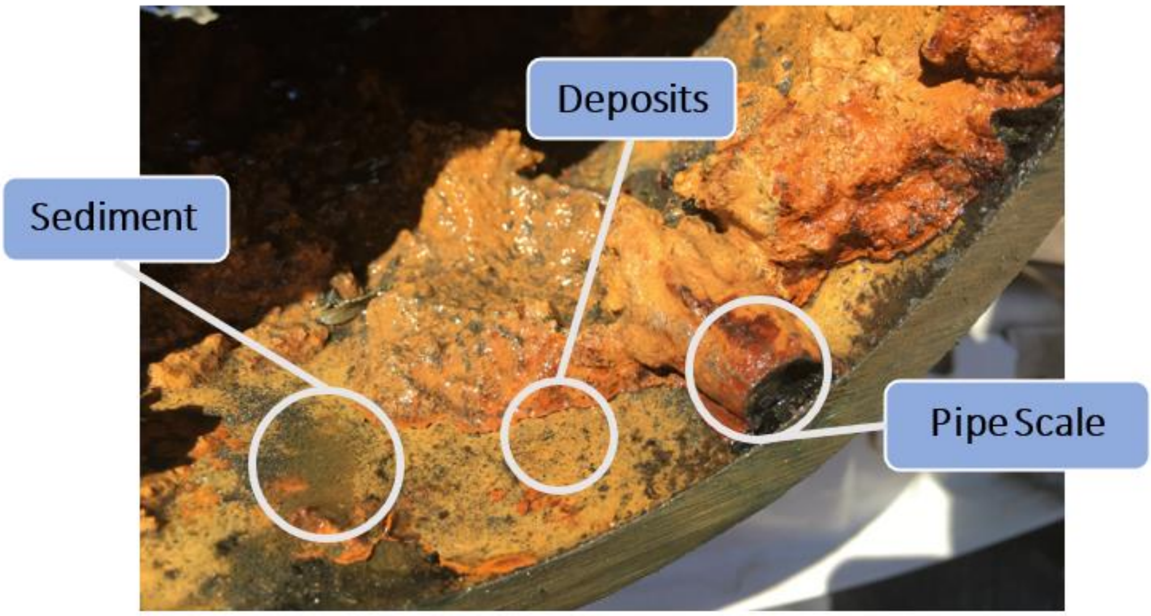
Figure 4: Cementitious Deterioration

It is important to have an awareness of corrosion and the effect it can have on the system in its operating environment. This is a key consideration when assessing the possible consequences of the addition of chlorine to an existing network. As presented, a significant proportion of material damage and subsequent component failure caused by corrosion can be eliminated by selecting the appropriate materials of construction for a given application.

3.2 SOLUBILISING LEGACY DESPOSITS

Operational pipes which have been in service for a period of time may contain scale, legacy deposits and sediment. The degree to which build up in the pipe occurs is dependent on material and water quality. Examples of different types of build-up within a pipe are shown in Photograph 1. This is the cross section view of a cast iron pipe. As with corrosion, this build-up can occur at the water treatment plant, in the distribution system and through household plumbing (Vendrell and Atiles, 2003).

Pipe scale is from corrosion deposits which form over time and attach to the pipe's inner walls (see Section 3.1 Corrosion of Pipes). This is through a process known as tuberculation in iron pipes and is dependent on the chemical resistance of the pipe material. Deposits are caused by minerals, primarily calcium and magnesium (Alpers, 2018). The amount of mineral content that water contains determines the hardness level of the water, measured in equivalent milligrams of calcium carbonate per litre of water. The Drinking Water Aesthetic Values 2022 state that hardness (total = Ca + Mg) shall be less than or equal to 200 mg/L calcium carbonate to avoid excessive scale deposition and scum formation (this is also pH- and alkalinity-dependent). It is also noted that low hardness (less than 100 mg/L calcium carbonate) may mean that water is more corrosive. The taste threshold is 100 – 300 mg/L calcium carbonate.



Photograph 1: Iron Pipe Cross Section with Scale, Sediment and Deposits

Again an understanding of the types of materials and water quality in an existing system is vital for predicting the type of scale, legacy deposits and sediment loading which may be present. It is then necessary to consider how this may react in the presence of chlorine. Dosing chlorine into an existing drinking water supply system which has not previously been chlorinated could result in solubilising scale and legacy deposits which have built up over time. This can result in the release of metals, minerals and sediments into the drinking water causing aesthetic issues through the discolouration of water and potentially health concerns depending on the types of legacy deposits.

3.3 SLOUGHING OF BIOFILM

A biofilm is comprised of extracellular material excreted by bacteria and is formed by a collection of organic and inorganic (living and dead) material which accumulates on a surface. It may be a complete film or, more commonly in water systems, small patches on pipe surfaces (LeChevallier, 1999). Photograph 2 shows the build-up of a biofilm within an iron section of pipe. These biofilms can form at any point within the water supply scheme. Biofilms allow microorganisms to persist, even in nutrient-poor systems and in drinking water pipe networks, and can be responsible for a wide range of water quality and operational problems.

Photograph 2: Iron Pipe Cross Section showing Biofilm

Biofilms may be more prominent in a system which has not previously had residual disinfection. When chlorine is first added to the system a breakdown/loosening of the biofilm (known as sloughing) may occur. In this case a significant portion of the chlorine may be consumed by the biofilm forming potentially harmful disinfection by-products and changes in taste and odour. It should be noted that although initially the addition of chlorine may result in changes in water quality due to reactions with the biofilm, the presence of this residual reduces the ability for the formation of new biofilm and consequently reduces the likelihood of microbial contamination within the network.

4 CHLORINE START-UP CONSIDERATIONS

Prior to switching chlorination on there are some key start-up considerations. The most important from an operational point of view is hydraulic cleaning (also known as flushing) of the distribution system. Flushing is best practice and can be used to both move water and clean pipes.

In relation to cleaning of pipes prior to chlorine dosing, flushing is used to:

- Remove sediment and deposits – scour the pipe to remove sediment and deposits (i.e. Fe, Ca, Al, trace inorganics).
- Remove biofilm – scour the pipe to remove accumulated bacteria and biofilm
- Prevent deposition – proactively manage the rate of accumulation

This ties in with reducing the impacts on distribution system infrastructure and water quality as discussed in Section 3.

Flushing can also be used to move water and achieve the following:

- Restore chlorine residual - bring in fresh water to increase chlorine residual.
- Reduce water age – create an artificial water demand to temporarily reduce water age
- Remove off-spec or non-compliant water – restore water quality in response to consumer water quality complaint

There are two types of flushing which are commonly used and can be applied to achieve either cleaning or to move water these are, unidirectional flushing (Figure 5) and conventional flushing (Figure 6).

The objective of unidirectional flushing is to remove accumulated solids/deposits to clean the watermain. This is done by pulling the water from one direction by closing valves and flushing systematically from a clean source. This achieves a higher velocity and a hydraulically cleaned watermain. The aim is to remove sediments and deposits and leave pipe scale intact (refer to Photograph 1). To achieve removal of sediment need to achieve a velocity ≥0.75 m/s and to remove deposits need a velocity of ≥1.5 m/s. The appropriate maximum flushing velocity is dependent on whether the pipe is scale-forming (i.e. cast iron) or non-scale forming (i.e. PVC). Scale-forming pipe can typically withstand velocities of 1.2 – 1.5 m/s and non-scale forming pipe ≥2.4 m/s.

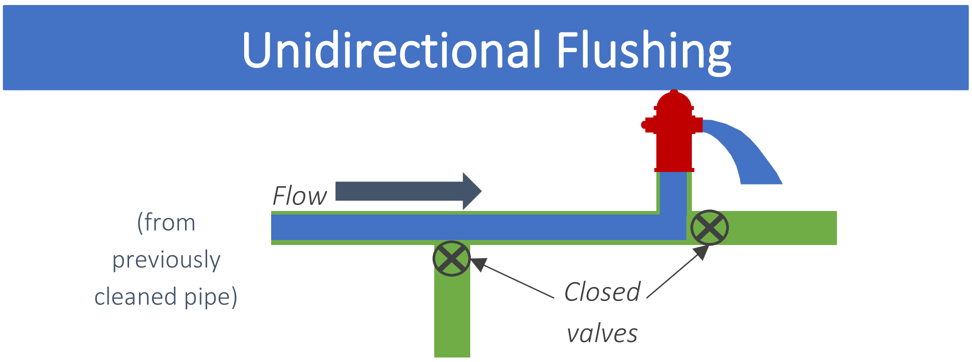


Figure 5: Unidirectional Flushing

The objective of conventional flushing in relation to chlorine dosing is to bring in fresh water to achieve/restore a chlorine residual. This is done by opening a hydrant and water being pulled from multiple directions. This flushing has an uncontrolled velocity which is often lower than unidirectional flushing so no cleaning effects are observed.

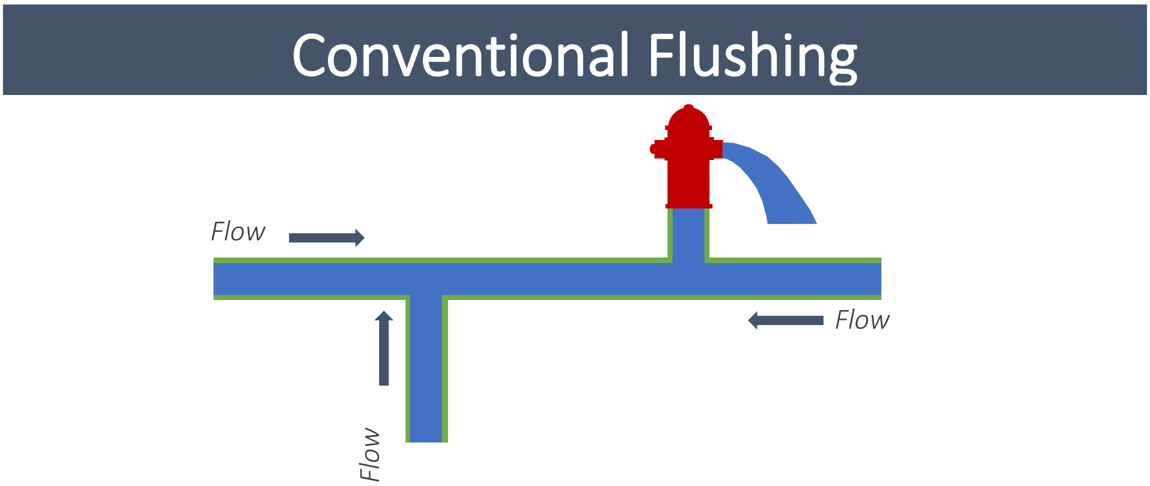


Figure 6: Conventional Flushing

Installation of chlorine infrastructure which accounts for the considerations in Table 1 and a start-up procedure that involves flushing and clear communication with consumers are key steps to successful introduction of chlorine to an existing network.

5 CHRISTCHURCH CITY COUNCIL'S WATER SUPPPLY SCHEMES

5.1 CHRISTCHURCH CITY COUNCIL'S APPROACH

The ability to provide residual disinfection following a transgression event and the requirements to be granted a chlorine exemption from Taumata Arowai has been a motivating factor for CCC to upgrade from temporary chlorination facilities to permanent standby chlorination infrastructure. Christchurch City has a decentralised system of multiple wells that provide high quality deep aquifer groundwater straight into the reticulation system for customer consumption (Christchurch City Council , 2021). There are 150 wells located across the city and all feeding into one combined network.

Figure 7 shows a high level process schematic with the key components of the permanent standby chlorine dosing systems which have been installed or are in the process of being installed.

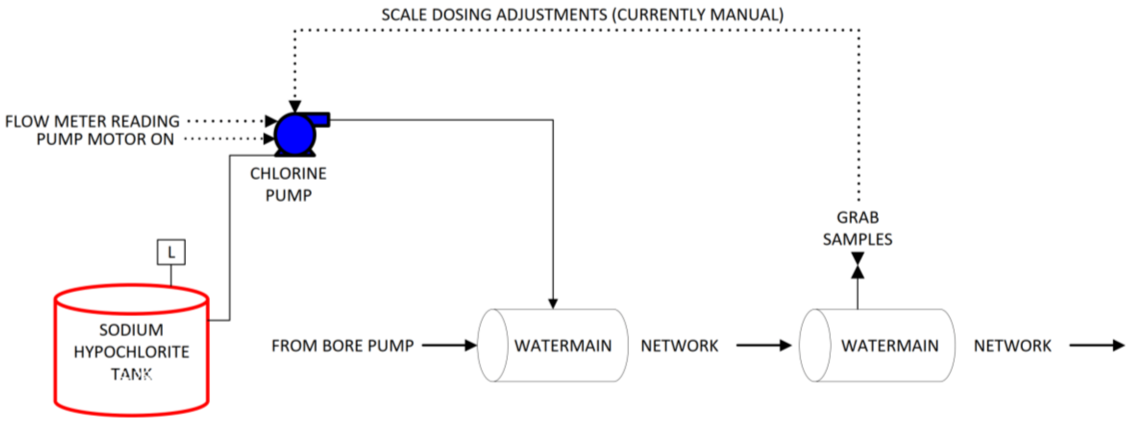


Figure 7: Hypochlorite Dosing Schematic

As water is pumped from a well, sodium hypochlorite from the chemical storage tank is dosed via a dosing pump into the centre of the watermain through an injection quill. Grab samples are taken from the purpose-built sample points. As shown in Figure 7, flow-paced dosing of chlorine is used. This means the dose rate is scaled from flow through the watermain. Grab samples are taken and used to scale and make adjustments to the chlorine dosing rate. Grab samples are also taken at the extremities of the network to monitor chlorine residual.

Current alarms include chlorine pump fault and chlorine tank level switches. Moving forward, CCC are looking to implement continuous chlorine tank level monitoring and online FAC monitoring with associated alarming to improve monitoring, control and reporting practices.

5.2 EXAMPLES OF IMPACTS ON THE WATER SUPPLY SYSTEM

5.2.1 CORROSION

Corrosion on pipe exterior around dosing points has been observed. This was especially prevalent at dosing points where pressure in the watermain is high. Dosing is via a removable injection quill, where injection quills are installed in high pressure parts of the water supply scheme the external connection points have been observed to vibrate. This causes the sodium hypochlorite to leak and therefore exposes pipes and equipment to chlorine resulting in corrosion.

Key lessons-learned from this are to proactively manage potential chlorine fumes and leaks to minimise the impact of corrosion on other infrastructure/equipment and to consider ease of access to the injection point for maintenance and observation. One way of achieving this is to install chlorine equipment in a separate room , and dose chlorine above ground or in an accessible chamber to allow for changeout of the injection quill if required. Looking forward, CCC are planning to gather more evidence by removing and inspecting injection quills to identify if corrosion of the quill has occurred. If corrosion has occurred it will also enable CCC to develop a renewals schedule of injection quills as part of routine operations and maintenance. It may also enable some analysis as to the impact of mixing and whether there is any difference in the amount of corrosion observed directly downstream of the injection point.

5.2.2 SOLUBILISING OF LEGACY DEPOSITS AND SLOUGHING OF BIOFILM

As described in Section 4.1 CCC take grab samples at the pump station to inform dosing control adjustments as well as in the distribution system to monitor the residual chlorine levels. The difference between the residual level at the extremities of the network and the pump station is the system's chlorine demand (Section 2.2). CCC have observed differences in the start-up chlorine demand between different water supply schemes.

When chlorine was first added to parts of the network the chlorine demand was high, virtually no residual was measured at the extremities. There were also several hundred consumer complaints in the first month of chlorination relating to the odour and taste of the drinking water, over time the level of complaints has reduced to a steady number of around 10 – 15 per month. This initial chlorine demand and number of complaints is believed to be related to consumption of chlorine due to reaction with the biofilm and possibly legacy deposits.

CCC took a proactive approach to communications for chlorine start-up at the Little River Water Supply Scheme and received no consumer complaints as a result of chlorine start-up, highlighting the critical importance of public engagement and expectation-setting.

As discussed earlier both the sloughing of biofilm and solubilising of legacy deposits induced by chlorine can result in increased chlorine demand and aesthetic water quality issues. The degree of this is influenced by pipe material types and source water quality. It is important to monitor the chlorine demand of the network and consumer complaints as these can provide a good indication that sloughing of the biofilm is occurring. A learning is also that proactive public communication is key. Drinking water can be a sensitive subject and changes in operation can impact the aesthetic properties of drinking water. If unmanaged these can erode public trust.

6 STEPS TAKEN TO MINIMISE IMPACTS

6.1 INSTALLATION OF CHLORINE INFRASTRUCTURE

There are pragmatic steps which can be taken as part of installation of chlorine infrastructure and the dosing start-up procedures. These steps reduce the impacts on both safety of water supply and longevity of the water supply infrastructure.

Some key considerations for the installation of equipment and how these were applied by CCC as part of the chlorine retrofit is summarised in Table 1. These considerations will also be applied as renewals take place. The Christchurch City Water Supply Scheme is a living asset with ongoing renewals and upgrades a normal part of the asset lifecycle. It should be noted that these tables include the ideal solution, which is to be implemented for standardisation where possible; it is also recognised however that as part of retrofitting equipment it may not be practicable to achieve the ideal solution and some customisation may be required for specific installations.

Table 1: Chlorine Infrastructure Retrofit Installation Considerations

No.	Installation Consideration	Implementation by CCC (where possible)	Reason
1	Material selection	Use of material that is suitable to convey or store chlorinated water: • Above-ground pipework will typically be steel (galvanised or stainless). It should be noted that steel pipework is vulnerable to corrosion however with the installation of a removable pipe spool, adequate mixing, and fine dosing control, the risk of corrosion is mitigated and ultimately outweighed by other benefits gained from using galvanised or stainless steel pipe in this application. • Below ground pipework will typically be polyethylene or polyvinyl chloride which is resistant to corrosion.	Reduces the likelihood of premature failure of equipment and pipes and reduces the likelihood of introduction of dissolved constituents into the water.
2	Pipe corrosion directly upstream and downstream of dosing point	Dose into a removable and accessible pipe spool (above ground is preferred)	Pipe is exposed to highest concentrations of chlorine at the dosing point, so the likelihood of impacts described above (Section 2.3.1 – 2.3.4) occurring is greatest. If damage occurs can replace this spool.
3	Adequate mixing	Dose via a static mixer or provide a minimum distance between dosing point and additional infrastructure (i.e. pumps, valves etc) and first consumer connection	Good mixing exposes the consumer to less variability in the chlorine concentration, speeds chlorine dispersion and allows for more accurate FAC monitoring.

No.	Installation Consideration	Implementation by CCC (where possible)	Reason
4	Fine level of dosing control and dosing control philosophy (flow paced or setpoint based)	Equipment selected which maintains a fine level of dosing control and a flow paced dosing philosophy applied	Reduces the likelihood of overdosing (especially at low flows and during changes in flow) and exposing consumers and infrastructure to variable concentrations of chlorine. Dose to flow rate ratio can be fine-tuned throughout operations to meet the target minimum residual.
5	Isolation of sodium hypochlorite tank and dosing equipment from other infrastructure/ equipment	Install sodium hypochlorite tank and dosing equipment in a separate room from other infrastructure	Reduces potential for corrosion of co-located assets.

7 CONCLUSIONS

The decision was made by CCC to install permanent standby chlorination infrastructure to reduce the residual risk to consumers and to align with requirements for a chlorine exemption.

It is known that chlorine is an oxidant and therefore results in some effects on the water supply system. These impacts include corrosion, solubilising of legacy deposits and sloughing of biofilm. Corrosion degrades the useful properties of materials and results in a loss of strength and increased permeability. Solubilising of legacy deposits and sloughing of biofilm results in the release of metals, minerals and sediments into the drinking water. This can cause aesthetic issues and potentially health concerns depending on the types of deposits.

Some impacts from chlorine in the Christchurch Water Supply Scheme were observed. Corrosion has occurred on external pipework surrounding the injection point. Further investigation into corrosion inside the watermain is also underway. Sloughing of biofilm and solubilising of legacy deposits was also monitored through the change in chlorine demand over time and the number of consumer complaints relating to aesthetic issues.

The magnitude of these impacts is dependent on several factors including pipe material and water quality characteristics. CCC have learned that there are several installation considerations which minimise the impacts of chlorine dosing on an existing system and consequently drinking water consumers. These considerations include material selection, location of dosing point, adequate mixing, dosing control and location of dosing equipment relative to other infrastructure. There are also some key operational start-up considerations that involve network flushing and clear communication with consumers all of which give implementation of chlorine the best chance of success. The purpose of chlorine in water treatment is to provide water which is safe to consume. To achieve this outcome it is vital to understand and manage the impacts of chlorine in a water distribution system. These lessons learned also have relevance to installations of fluoridation, a topic which numerous water suppliers across New Zealand are currently considering.

ACKNOWLEDGEMENTS

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REFERENCES

Alpers, C. (2018) *Pipe Scale Studies at Iron Mountain Mines.* USGS, United States of America.

American Water Works Association. (2006) *Water Chlorination/Chloramination Practices and Principles.* American Water Works Association, United States of America.

Centers for Disease Control and Prevention. (2013) *Drinking Water Pipe Systems.* U.S Department of Health & Human Services, United States of America.

Centers for Disease Control and Prevention. (2022) *Free Chlorine Testing.* U.S Department of Health & Human Services, United States of America.

Choi, Y., Byun, S., Jang, H., Kim, S. and Choi, Y. (2021) *'Comparison of disinfectants for drinking water: chlorine gas vs. on-site generated chlorine',* Environmental Engineering Research, 27, 1, 1-2.

Frankel, G. (1998) *'Pitting Corrosion of Metals: A Review of Critical Factors',* Journal of The Electrochemical Society, 145, 6.

LeChevallier, M. (1999) *Identifying Future Drinking Water Contaminants.* National Academies Press, Washington DC, United States of America

McCafferty. (2010) *Introduction to Corrosion Science.* Springer, Switzerland, 13-31.

Ministry of Health. (2018) *Drinking Water Standards for New Zealand (Revised 2018).* Ministry of Health, Wellington, New Zealand.

Młyńska, A., Zielina, M. & Bielski, A. (2019) *'Contamination of drinking water soon after cement mortar lining renovation depending on the disinfectant doses'* SN Applied Sciences, 1, 516.

New Zealand Government. (2021) *Water Services Act 2021.* New Zealand Government, Wellington, New Zealand.

New Zealand Government. (2022) *Water Services (Drinking Water Standards for New Zealand) Regulations 2022.* New Zealand Government, Wellington, New Zealand.

Safe Drinking Water Foundation. (2022) *What is Chlorination Fact Sheet.* Safe Drinking Water Foundation, Saskatoon, Canada.

Tait, W. (2018) *Handbook of Environmental Degradation of Materials (Third Edition).* Science Direct, 583-600.

Taumata Arowai. (2022) *Drinking Water Quality Assurance Rules 2022 (Released 25 July 2022).* Taumata Arowai, Wellington, New Zealand.

Taumata Arowai. (2022) *Aesthetic Values for Drinking Water Notice 2022.* Taumata Arowai, W

Vendrell, P.F. and Atiles, J.H. (2003) *Your Household Water Quality: Corrosive or Scaling Water.* The University of Georgia, Athens, United States of America.